Neurology & Neurophysiology

Corradini and Persinger, J Neurol Neurophysiol 2013, 4:5
http://dx.doi.org/10.4172/2155-9562.1000175

Research Article Open Access

Brief Cerebral Applications of Weak, Physiologically-patterned Magnetic Fields Decrease Psychometric Depression and Increase Frontal Beta Activity in Normal Subjects

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Abstract

Background: Brief (30 min to 60 min) applications of weak, physiologically-patterned magnetic fields have been demonstrated to produce analgesia in rodents and reduction of depression in patients who have sustained Traumatic Brain Injuries (TBI). To discern if the effects from one effective field pattern could be measured by quantitative electroencephalography (QEEG) and reflected in psychometric inferences of depressed mood, normal volunteers were measured.

Methods: A total of 22 normal volunteers were exposed for 30 min to sham field conditions or to a burst-firing magnetic field (1 μT) that was applied across the temporal lobes during QEEG measurements. The Profile of Mood Scores short-form (POMS-sf) was administered before and after the exposures and correlations between these scores and bands of QEEG power were completed.

Results: The subjects exposed to the burst-firing magnetic field displayed a significant decrease in depression scores compared to those exposed to the sham fields. The treatment effects accommodated about one-quarter of the variance in scores. Like previous studies the other components of the POMS-sf did not differ significantly between treatments. Field exposed subjects displayed significant increases in beta power over the prefrontal regions and left temporoparietal areas the magnitude of which was strongly correlated with the depression mood scores.

Conclusion: Brief exposures to weak, physiologically-patterned magnetic fields that can be generated by contemporary computer systems produced reliable changes in QEEG activity and were even reflected in relatively insensitive psychometric indicators in normal individuals. The development of this technology for self-treatment of patients who have sustained TBIs may be a useful adjunctive therapeutic intervention.

Keywords: Quantitative electroencephalography; Depression; Transcerebral weak magnetic fields; Burst-firing patterns

Introduction

An essential assumption in contemporary Neurology and Neurophysiology is that cognition and subjective experiences are strongly correlated with the quantitative changes within global cerebral activity. Experimental modification of changes in cognition and emotion require the effective stimulus to traverse the cerebral volume. Historically this has been accomplished by pharmacological agents whose delivery to the appropriate (synaptic) space within the brain is strongly dependent upon the microstructual distribution of vascular and blood flow. Considering the specificity and selectivity of the blood-brain-barrier, this is also a limiting factor.

The alternative strategy is to apply appropriately patterned magnetic fields that have the capacity to penetrate the cerebral volume. Two recent methodologies have emerged. The first involves the application of strong Tesla-level pulsed fields, TMS (Transcranial Magnetic Stimulation). There is strong evidence that the strategic application of these focal fields over discrete areas can affect cognition [1] and affective [2] behaviours. The mechanism by which these change occur is assumed to be a Faraday-like induction of relatively strong electric currents within populations of neurons.

A second approach is to employ much weaker and easily available temporally patterned magnetic fields that are applied across the horizontal plane of the cerebrum at the level of the temporal lobes [3,4]. The assumption is that the energy contained within the magnetic field in conjunction with its temporal patterns facilitated resonance [4] within particular intracerebral structures that enhance their function. There is experimental evidence involving rodent brains that the electrically labile brain after traumatic brain injury is particularly sensitive to the beneficial effects of very specific patterns of applied magnetic fields whose precise temporal patterns simulate the intrinsic properties of local populations of neurons [5].

The configurations of these fields are generated from computer software by transforming a series of integers between 0 and 256 to discrete voltages between -5 to +5 V that are then delivered by digital-to-analogue converters to arrays of small solenoids. They are placed in specific areas on both sides of the subject's head. The fields, which are typically a million times weaker (1 microTesla) than those involved with TMS, are structured to penetrate through intervening cerebral volume. That these weak, temporally-patterned magnetic fields penetrate the physiological equivalents of brain tissue has recently been shown experimentally [6]. In fact direct measurements clearly indicated there

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Received October 31, 2013; **Accepted** November 26, 2013; **Published** December 04, 2013

Citation: Corradini PL, Persinger MA (2013) Brief Cerebral Applications of Weak, Physiologically-patterned Magnetic Fields Decrease Psychometric Depression and Increase Frontal Beta Activity in Normal Subjects. J Neurol Neurophysiol 4: 175. doi:10.4172/2155-9562.1000175

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was no significant attenuation of the strength of the field when it was generated through substances that simulated the density and thickness of the human skull.

Baker-Price and Persinger [7,8] found that weekly approximately one hour presentations of a patterned magnetic field across the temporal lobes of individuals who sustained closed head injuries secondary to mechanical trauma to the skull showed remarkable reduction in subjective reports of depression as measured by psychometric tests and clear clinical improvement in adaptation. The pattern of the magnetic field was a repeated series of accelerating [9] pulses contained in a packet with each packet being presented for 690 ms followed by 4 s of no stimulation before the packet occurred again. This same pattern produced analgesia in rats [10] that was comparable to the effects of 4 mg/kg of morphine.

The application of this technology to individuals with different degrees of brain injury has both clinical and humanitarian potential. However if the effects are similar to those associated with pharmacology, then there would exist not only the equivalent of "dose dependence" and "molecular structural specificity" but varying efficacy for different populations. In a previous experiment Tsang et al. [9] exposed a total of 56 normal young men and women to either daily (for three consecutive days) or weekly (for three consecutive weeks) to transcerebral presentations of various temporal patterns of 1 μT magnetic fields. Each treatment was 20 to 30 min in duration. A psychometric measure of mood states was given before and after each treatment.

The patterns included the burst-firing pattern that was found to be efficacious by Baker-Price and Persinger [7,8], those that involved random sequences and configurations that, when applied as electrical pulses to hippocampal slices, induce LTP (long term potentiation). The latter is the most common neurophysiological correlate associated with long-term consolidation of memory. Two obvious results emerged. First, weekly treatments rather than successive daily treatments were more effective for producing clinically relevant magnitudes of change, that is, effective sizes that explained more than 50% of the pre-post test variance in mood scores. Secondly, different patterns produced different changes in the dimensions of confusion, vigour, fatigue, anger, depression and tension. In that study the same pattern that produced the relief of depression in patients who had sustained TBI, the burst-firing pattern, produced the greatest decrease in "depression" scores for these normal volunteers. The present study was designed to systematically replicate and extend the results by Baker-Price and Persinger [7,8] by using university volunteers and adding quantitative electroencephalographic measurements (QEEG).

Materials and Methods

This experiment was designed to discern the effect size of the magnetic field upon mood and electroencephalographic measures. Twelve men and thirteen women (n=25), who were enrolled in undergraduate university psychology courses, volunteered as subjects. They were motivated by bonus marks for final grades in the appropriate courses. With the permission of the course instructor, the primary researcher recruited the participants from within the classes using a script that had been preapproved by the universities Research Ethics Committee. Each participant was individually tested. Each participant signed a consent form indicating that they may or may not be exposed to a weak complex magnetic field. Without their knowledge they were assigned randomly to either a field or sham-field condition. Prior to any treatment a demographics questionnaire and the Profile of Mood States (POMS; 30 item short-form) was administered. The POMS-sf required the participants to read a list of words that describe feelings people have and then indicate on a Likert scale (0=not at all to 4=extremely) which best described how they had been feeling during the previous week (Table 1). This was similar to the psychometric tool employed by Tsang et al. [9,10]. The participant was then seated in a comfortable chair connected to both the quantitative electroencephalograph (QEEG) and to the magnetic field device. The subjects were blindfolded to reduce sensory stimulation (Table 1).

A Grass model P79 quantitative electroencephalograph measured their cortical electrical activity. Sensors were placed on the scalp using the international 10-20 system of electrode placement. Eight scalp sensors were placed over approximately F7, F8, P3, P4, T3, T4, O1 and O2 (which corresponds to the left and right frontal, parietal, temporal and occipital lobes, respectively). For this study a monopolar montage was used and so a reference electrode was placed on the left ear.

The magnetic field was generated by a Zenith 159 computer. The signal from the computer was created by software [11] and was amplified by a digital-to-analogue converter (DAC) and a d.c. (operational) amplifier. The signal source was sent to the signal distribution interface (semiconductor switches) that was controlled by a sequencer. From the sequencer the signal was interfaced with two sets of four solenoids (250 ohm coils from 5 V DC relays, with the reed removed and replaced with a small steel finishing nail).When the solenoids were activated, the field strength along the external edge of the skull was 10 to 20 milligauss or 1 to 2 microTesla.

The signal shape generated by the computer simulated the burst-firing pattern of amygdaloid neurons (as shown in Figure 1). This burst-firing magnetic field was applied through the bilateral temporoparietal regions through pairs of 4 solenoids that were within 2 small containers. The pattern was created by a simple conversion of a series of numbers between 1 and 256 to voltage output; values below 127 were negative polarity while those above 127 were positive polarity. The duration of each of the 230 successive temporal points that constituted the wave were programmable. The point duration for each value (a number between 1 and 256) of the serial 230 numbers that were converted into voltages (-5 to +5 V) that produced the magnetic field through the arrays of solenoids was 3 ms. This particular, programmable, point duration has produced the most effective changes for analgesia in rats. Point durations of 1 ms or greater than 4 ms are not effective. The technology was the same as that which has been shown to improve protracted moderate depression (over several years) in patients who had sustained TBIs during motor vehicle incidents [7,8].

Once participants were connected to both the QEEG and magnetic field apparatus baseline recordings were taken: 30 seconds with the participant's eyes open and 30 seconds with the participants eyes closed. Once the baseline recordings were completed participants were

Word list		
Tense	Unworthy	Gloomy
Angry	Uneasy	Sluggish
Worn out	Fatigued	Weary
Lively	Annoyed	Bewildered
Confused	Discouraged	Furious
Shaky	Nervous	Efficient
Sad	Lonely	Full of pep
Active	Muddled	Bad-tempered
Grouchy	Exhausted	Forgetful
Energetic	Anxious	Vigorous

Table 1: Word list from profile of mood states – short-form.

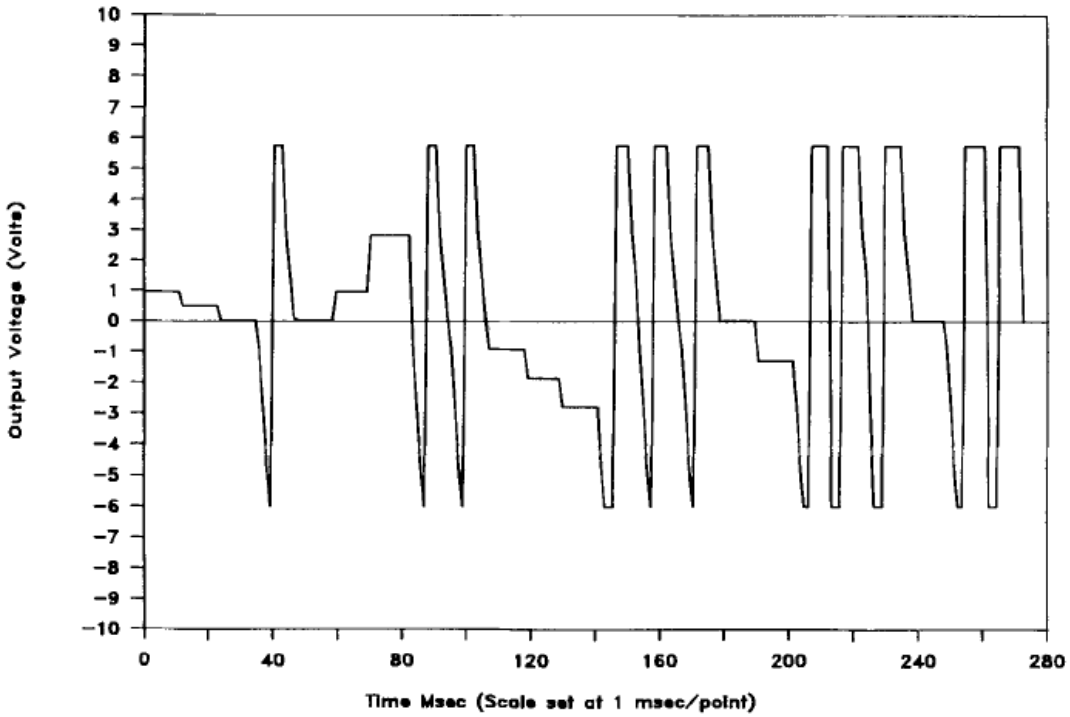

Figure 1: The burst-firing pattern that was generated by converting a series of preprogrammed successive numbers by a computer software to voltage (y-axis). In our study the point durations were 3 ms.

asked to relax with their eyes closed for 30 minutes while they were either exposed to a sham magnetic field (no field) or the treatment magnetic field (burst-firing patterned magnetic field). The 30 minutes of treatment was segmented by the experimenter into 10 minute sections in order to compare the participant's brain activity over time.

When the treatment of 30 minutes was complete participants were exposed to one of three narratives containing positive, negative, or neutral emotional words [7]. The duration of each narrative was 3 min and was delivered by tape recorder to ensure consistency. The purpose of these narratives was to simulate the effects of post-magnetic field treatment therapeutic instructions. Because there was no difference in either mood scores or QEEG profiles between the types of narratives their distinction was not considered for the remaining analyses. A second set of baseline recordings was taken again for 30 seconds with eyes opened followed by 30 seconds with eyes closed. Subjects were disconnected from both the QEEG and the magnetic field apparatus, administered the post profile of mood states questionnaire and debriefed.

All QEEG data (baseline recordings and experimental recordings) was screened for muscle, eye and likely magnetic field artefacts using the freeware program EEGlab. The corrected QEEG data was Fast Fourier transformed and the power outputs were analyzed for seven frequency bands [delta (1.5-4 Hz), theta (4-7.5 Hz), low alpha (7.5-10.5 Hz), high alpha (10.5-14), low beta (14-20 Hz), high beta (20-30 Hz), and gamma (30-40 Hz)].

Results

An analysis of variance of the 6 POMS subscales by field condition (sham field or treatment field) showed an effect for only the depression subscale. There were no statistically significant changes in the other five types of mood. Figure 2 illustrates the results of this analysis that indicated a statistically significant decrease in depression scores for participants who were exposed to the treatment magnetic field compared to the group of participants who were not exposed to the magnetic field [$F_{(1,24)}$=8.85, $p<0.01$, η^2=0.28].

Figure 3 shows that when relative high beta (20 to 30 Hz) power was analyzed the participants exposed to the treatment magnetic field displayed significantly more overall relative high beta power when compared to the no field (sham) condition [$F_{(1,24)}$=5.95, p=0.023, η^2=0.21]. No other frequency band demonstrated a statistically significant treatment effect.

A factor analysis was completed for the voltage fluctuations for the 8 individual sensors after 10 minutes of field (or sham) exposure in the high beta frequency band. This analysis revealed 2 factors (factor 1=P3, T5, F7, F8 and factor 2=O1, O2, P4, T4). These two factors were then correlated (taking into account field group) with the change in depression scores. Results revealed that factor 1 was negatively correlated with the POMS-sf change in depression scores (rho=-0.61, p=0.03) indicating that when the treatment field was present in conjunction with a relatively higher power in beta activity there was a decrease in post-session scores for "depression" according to the POMS.

Discussion

These results reiterate and extend the measurements of Tsang et al. [7,9] who showed that normal volunteers who were exposed weekly to the same burst-firing magnetic field reported less intense mood indicators by which psychologists infer the construct of depression. In fact this pattern of repeated presentations of a burst of 10 pulses with increased frequency-modulation within a 690 ms period followed 4 s with no field was more effective in the Tsang study than more complex magnetic field sequences, sham exposures, or random sequences

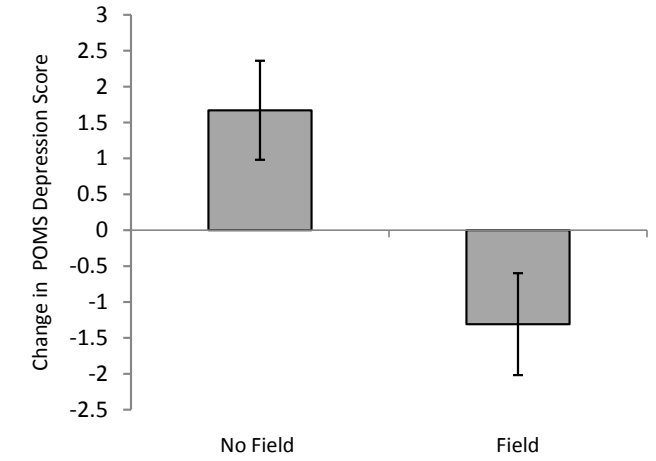

Figure 2: Effect of the treatment magnetic field on the profile of mood states depression subscale scores (means ± SEMs).

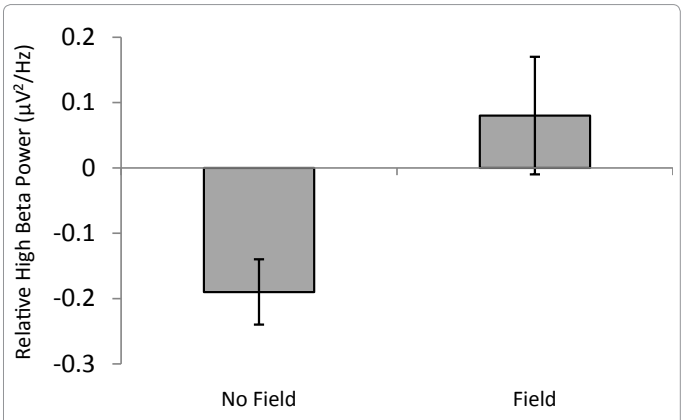

Figure 3: Effect of the treatment magnetic field on relative high beta power (means ± SEMs).

of magnetic fields. These results emphasize the importance of the *temporal pattern* of the applied magnetic field in a manner analogous the molecular structure of medications. In addition Tsang's study showed that different mood ratings, particularly when the weekly magnetic field exposures were involved, were responsive to different patterns. However Tsang et al. [7,9] did not employ concurrent electroencephalographic measurements.

The normal volunteers in the present experiment displayed a comparable effect size for the change in depressive mood scores. The quantitative decreases in the psychometric inference of mood were correlated with an increase in general cerebral power within the beta range of electroencephalographic activity but only for those subjects that had been exposed to the magnetic field treatments. Factor analyses indicated that the region of increased beta activity involved the prefrontal areas of the brain, bilaterally and the left temporoparietal region. Historically activation of the left hemisphere is associated with elevated mood as well as increased sense of self. Conversely, decreased metabolic activity and generally diminished beta activity over the left hemisphere, particularly the left prefrontal region, is associated with clinical depression and diminished sense of self [12].

Our protocol was designed to simulate a clinical therapeutic session. Both the field-exposed and sham field-exposed groups listened to narratives. However only the magnetic field exposed group displayed the diminished scores for depressed mood. We suspect exposure to the burst-firing field for 30 minutes followed by the brief narrative contributed to the elevation of high (20 to 30 Hz) beta power within the left hemisphere of these subjects compared to the sham field group. The elevated power within the high beta range was not an artefact from the applied field. First the central frequency for the burst-firing pattern would be about 15 Hz if the packet was extended over one second. Secondly, the amount of power within this beta range was associated quantitatively with the change in mood ratings.

Although there are many pharmacological treatments that have been applied to patients who have sustained TBIs, a subset of patients often do not respond to medications. We have hypothesized that the refractory nature of this population may reflect the sampling procedure in drug screening studies. Antidepressant compounds are standardized within populations who were depressed because of endogenous factors or secondary to changes in social factors, such as grieving. Depression secondary to TBIs where neuronal populations may be compromised in a different manner may involve different chemical and electrical etiologies. This approach has been supported by recent imaging data in patients [13]. Experimentally induced TBIs employing the weight-drop method to the tops of the skulls in rats produced conspicuous histological patterns of diffuse scatter of shrunken neurons with intense Nissl stain under the impact site and at countercoup distances [14]. The forces were mild, evoked stunning rather than unconsciousness, much like many "mild brain traumas" during motor vehicle incidents, and did not involve "pain" as inferred by absence of vocalization in the rats. Subsequent exposure to patterned magnetic fields [15,16] reduced both the area and number of shrunken, anomalous dark staining neurons in the rats that had sustained these mechanical impacts to the skull.

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